Mobility, Mortality, and the Middle Ages: Identification of Migrant Individuals in a 14th Century Black Death Cemetery Population

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ABSTRACT Mobility and migration patterns of groups and individuals have long been a topic of interest to archaeologists, used for broad explanatory models of cultural change as well as illustrations of historical particularism. The 14th century AD was a tumultuous period of history in Britain, with severely erratic weather patterns, the Great Famine of 1315–1322, the Scottish Wars of Independence, and the Hundred Years' War providing additional migration pressures to the ordinary economic issues drawing individuals to their capital under more stable conditions. East Smithfield Black Death Cemetery (Royal Mint) had a documented use period of only 2 years (AD 1348–1350), providing a precise historical context (~50 years) for data. Adults (n = 30) from the East Smithfield site were sampled for strontium and oxygen stable isotope analyses of tooth enamel. Five individuals were demonstrated to be statistical outliers through the combined strontium and oxygen isotope data. Potential origins for migrants ranged from London's surrounding hinterlands to distant portions of northern and western Britain. Historic food sourcing practices for London were found to be an important factor for consideration in a broader than expected $^{87}Sr/^{86}Sr$ range reflected in a comparison of enamel samples from three London datasets. The pooled dataset demonstrated a high level of consistency between site data, divergent from the geologically predicted range. We argue that this supports the premise that isotope data in human populations must be approached as a complex interaction between behavior and environment and thus should be interpreted cautiously with the aid of alternate lines of evidence.

INTRODUCTION

Mobility and migration patterns have become a topic of vital concern in archaeology, following a long period of neglect (Anthony, 1990). Some archaeologists see migration as an aberration and confounding factor in the attempt to characterize and describe processes of broad cultural change, while others see the study of mobility as an opportunity to identify subcultures, kinship networks, and trade relationships through predictable patterns of migration (Anthony, 1990). In the latter view, migrants are the exception that proves the rule: in archaeological cultures as in modern society, individuals matter.

British migration patterns in the late medieval period are a little-explored field of enquiry in isotopic research (Muldner et al., 2009). Even more poorly illuminated, by documentary as well as biogeochemical study, is the period directly preceding the arrival of the Black Death in Britain. Furthermore, all of the mobility studies previously completed in Britain have used attritional cemetery samples, thereby limiting the scope of interpretation through poorly defined temporal resolution. This study will be the first to use a catastrophic cemetery of known and limited date, providing an unusual snapshot of migration during a period of immense change and development in European history.

IDENTIFYING PAST MOBILITY USING STABLE ISOTOPE ANALYSES

Unlike the proxy methods available through patchy historical documentary evidence, analyses of stable isotopes in archaeology offer a unique opportunity to address questions concerning past environmental conditions, subsistence strategies, and mobility through direct biogeochemical data derived from human and animal skeletal tissues. Current mobility studies often combine analyses of oxygen and strontium isotopes. While strontium is related to and derived from underlying geology through food sources, oxygen carries the advantage of being tied to meteorological trends through water sources, and hence to geographical climatic clines at a basic level (Budd et al., 2004; Evans et al., 2006; Eckhardt et al., 2009; Muldner et al., 2009; Chenery et al., 2010). Tooth enamel is optimal for these analyses, being inert once formed, and additionally resistant to post-depositional alteration (Lee-Thorp, 2008).

Strontium is an alkaline metallic earth element with variable geographical and geological distributions (Bentley, 2006). Strontium isotopes become bioavailable through weathering of strontium-bearing rocks and minerals into soils, and to a lesser extent, through atmospheric sources (Bentley, 2006). Once weathered into soils, the original terrestrial strontium may be leached into local hydrological systems (e.g., aquifers, oceanic bodies, or riverine networks) and enter the biosphere through the uptake of plants, which are in turn consumed by herbivores and omnivores. Due to shared chemical similarities, strontium isotopes readily substitute for calcium in the skeleton and are integrated into the bioapatite of bone and teeth. This relationship between geology and skeletal chemistry has been exploited in provenance studies from a wide range of geographical contexts (e.g., Sealy et al., 1995; Ezzo et al., 1997; Beard and Johnson, 2000; Price et al., 2000; Montgomery et al., 2005). The strontium isotope abundance most commonly analyzed in human and animal skeletal material is the radiogenic ^{87}Sr, which is normalized against the nonradiogenic ^{86}Sr, cancelling out variations in total strontium (Budd et al., 2004; Bentley, 2006).

Oxygen isotopes are bioavailable from multiple environmental reservoirs and fluctuate within the biosphere as they interact with human and animal life: they are breathed in from atmospheric sources, received in concentrated levels via food and water, and released in exhaled water vapor, carbon dioxide, and bodily fluids. However, the most significant contributor to mammalian intake is drinking water, with food as a secondary factor (Luz et al., 1984; Luz and Kolodny, 1985; Kohn, 1996; White et al., 2004; Daux et al., 2008). Drinking water is primarily derived from meteoric sources, although some may be obtained from aquifers reflecting longer term climatic trends (Fricke and O'Neil, 1996) and is tied to latitude by the behaviors of atmospheric precipitation (Brown and Brown, 2011). Thus, with both strontium and oxygen isotopes, it is possible to identify nonlocal individuals—and hence incidents of migration—through a comparison of skeletal and expected local isotope values.

Historic migration pressures

Expectation is often at odds with reality in the realm of medieval mobility. It is commonly assumed that travel over substantial distances within Britain was beyond the means or ability of most medieval people; this assumption has no basis in fact. Travel of 10 to 20 miles was commonplace, while ''London was exceptional and drew larger numbers from all over England'' (Childs, 2006, p. 269). Isotopic analyses offer a direct avenue of enquiry to address assumptions such as these. The 14th century produced famine, multiple wars, and pandemic disease, all potential reasons for increased population mobility over and above this normal baseline ebb and flow.

Between approximately A.D. 950 and 1400, the Northern Hemisphere experienced an interval of unusually mild weather, known as the Medieval Warm Period (MWP) (Lamb, 1965). These conditions produced ample harvests and consequent population growth (Jordan, 1996). Unfortunately, this period of relative abundance and prosperity was brought to an end by a shift in climatic conditions. The end of the MWP and the subsequent transitional period preceding the Little Ice Age (c. A.D. 1400–1900) was marked by environmental catastrophe: heavy rainfall and dropping temperatures, resulting in flooding, crop failure, and famine (Aberth, 2000). These were accompanied by a series of animal murrains affecting sheep and cattle, such as liver fluke, which severely limited the availability of meat and dairy products (Kershaw, 1973). No less severe than the dearth was the inflation in the price of food; this weighed heaviest on the common peasantry, who were least able to pay and whose staple diet was grain-based (Aberth, 2000).

Further insult to an already injured population came in the form of various plagues and epidemics described by contemporary historians (Lucas, 1930). An estimated 10%–25% of the population died due to famine-related causes (Jordan, 1996; Frank, 1997; Aberth, 2000), although how many died from simple starvation, how many from aggregate comorbidity of disease and malnutrition, and how many from diseases of dietary desperation, such as ergotism, is open to question. Dysentery and high fever are described as being extremely common precursors to death (Lucas, 1930; Frank, 1997). Foreshadowing the mass mortality of the later Black Death pandemic, it is recorded that ‘‘Death often came very suddenly, and the number of the dead was so great in many places that there were not enough persons sufficiently well to bury them’’ (Lucas, 1930, p. 357). Stories of murder and cannibalism, even of children by their parents, are recorded as being rife by the 14th century monastic chronicler Johannes de Trokelowe (Lucas, 1930; Aberth, 2000). Even if these statements are not taken at face value, they are at least testament to the impression made by the level of desperation prevalent to the period. Periods of famine in more recent recorded history have led to temporary increases in mobility as desperation has driven groups and individuals to leave home and security to seek out resources unavailable in their home area (O'Gráda, 2009). Traditionally, mobility has been viewed as the prerogative of young males, at least in the initial phase of migratory events (because males are seen as being less vulnerable to the dangers of lone travel) (Anthony, 1990; Prowse et al., 2007) and potentially carrying an urban-to-rural directionality (O'Gráda, 2009). However, history has not borne these assumptions out with any degree of consistency: during the Irish Great Famine of the 1840s, a total failure of the potato crop caused by blight, large numbers of women migrated from their rural villages to urban Dublin to engage in prostitution (O'Gráda, 2009). In times of desperation, rules are often suspended. Bailey (1998) emphasizes the importance of the question of rural-to-urban migrations in response to the crises of the 14th century, while noting the paucity of data available to address it. It is both reasonable and relevant to consider and investigate the possibility that during the Great Famine (A.D. 1315– 1322) rural British individuals may have sought out the greater financial and charitable resources available in the urban centers.

Large medieval cities, London in particular, depended on attracting economic migrants at regular intervals from rural areas to maintain labor forces, as birth-rates in cities rarely exceeded net mortality (Goldberg, 1996). This demand for migration would have increased as England became engaged in wars and an exodus of military manpower occurred. Two major conflicts were fought during the 14th century; the Anglo-Scottish Wars (AD 1296–1328 and 1332–1357) and the Hundred Years' War (AD 1337–1453). In both these conflicts, the English placed a heavy emphasis on archery and infantry, to devastating effect. This reliance on foot soldiers would have led to a high demand for troops, which would have not only facilitated migration to centers of enlistment but also increased economic migration from the hinterlands to replace the absent manpower, right up to the time of the Black Death.

East Smithfield and the Black Death

The Black Death is generally agreed to have arrived in Britain in the summer of 1348, probably through infection-bearing ships arriving via Melcombe Regis, a borough of Weymouth, Dorset (Hawkins, 1990; Antoine, 2008). By autumn of that year the first cases of plague were being reported in London (Horrox, 1994). The disease spread quickly and extensively throughout the kingdom, causing massive morbidity and mortality. Many who had it within their power fled the contagion, often futilely (Horrox, 1994), out of the towns and into the countryside, further spreading the disease. The introduction of the Black Death to London represents one of the greatest recorded demographic catastrophes in British history to date.

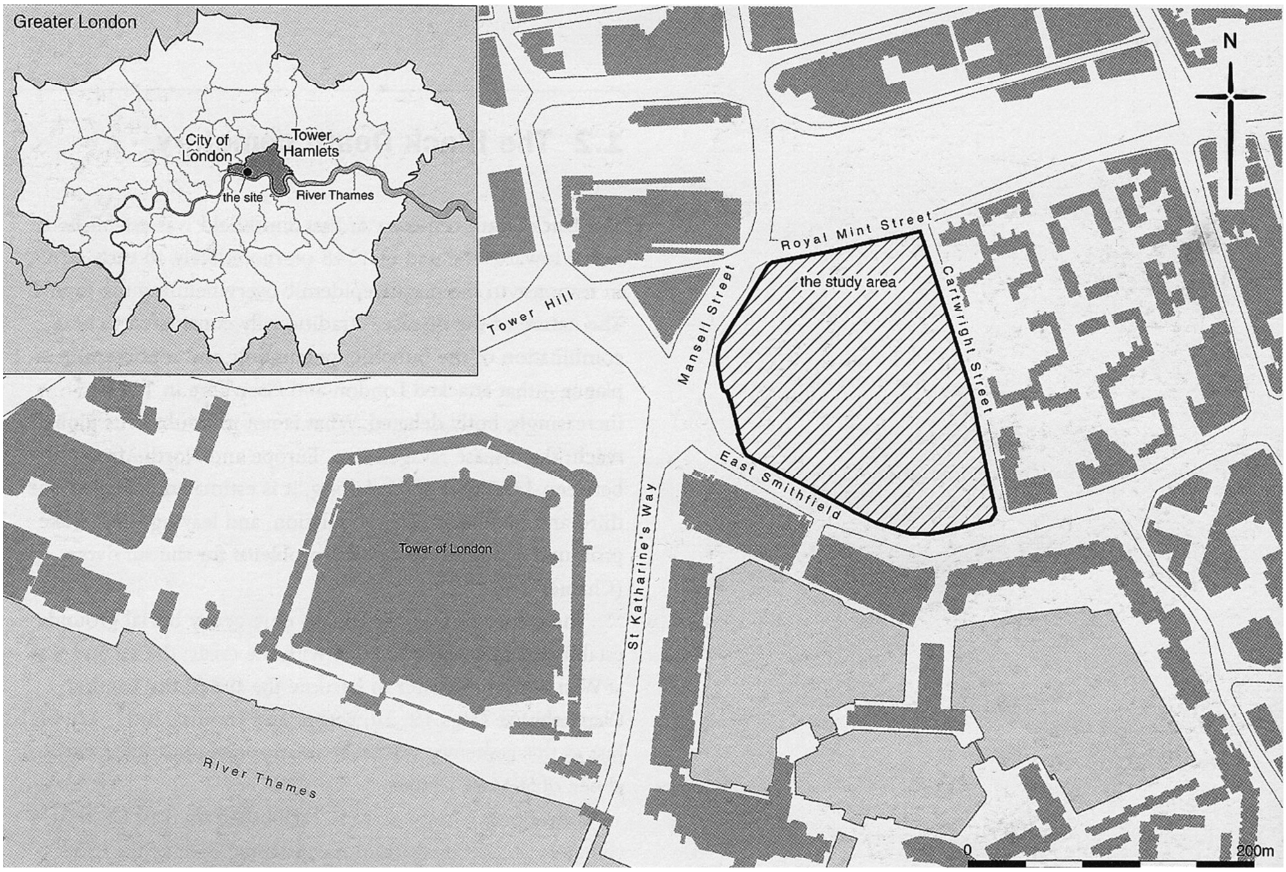

Fig. 1. Map of East Smithfield Black Death Cemetery Location (Grainger et al., 2008).

East Smithfield (Fig. 1) was one of two London properties purchased in 1348 by John Corey, a clerk in royal service, and consecrated by the Bishop of London to be used as an emergency burial ground to receive Black Death fatalities exceeding the capacity of existing cemeteries (Hawkins, 1990). The cemetery was used for the period 1348–1350 exclusively, and there is no documentary evidence to suggest it was used for internments after this period (Hawkins, 1990). Immediately following the abatement of the Black Death in 1350, Edward III founded a Cistercian abbey, St. Mary Graces, on the site. From the dissolution of the monasteries in the 16th century until the construction of the Royal Mint in the 19th, the site was left reasonably undisturbed, being used as a private manor and naval victualing yard in subsequent years (Grainger et al., 2008). The construction of the Royal Mint buildings led to substantial truncation, as well as damage to bone resulting from chemical contamination, occurring in the eastern burial area (Grainger et al., 2008).

The burial ground comprised two discrete main areas (Fig. 2), east and west, which were excavated over several seasons, beginning in 1986, by the Museum of London Archaeological Service as part of the Royal Mint project (Grainger et al., 2008). All burials were oriented east–west, with the majority of individuals lying in a supine position. The cemetery was greatly underutilized, with large unused areas; the Black

Death crisis apparently passed with lower mortality than was expected by authorities (Hawkins, 1990). The eastern area comprised one mass burial trench and four parallel north–south rows of graves, totaling 195 individuals, with both shroud and coffin burials represented. The grave burials were generally poorly preserved, due to contamination from the Royal Mint, leading to empty graves in some cases. The western area was much larger, with 566 burials distributed between two mass burial trenches, one mass burial pit, and 11 parallel north–south rows of graves (Grainger et al., 2008).

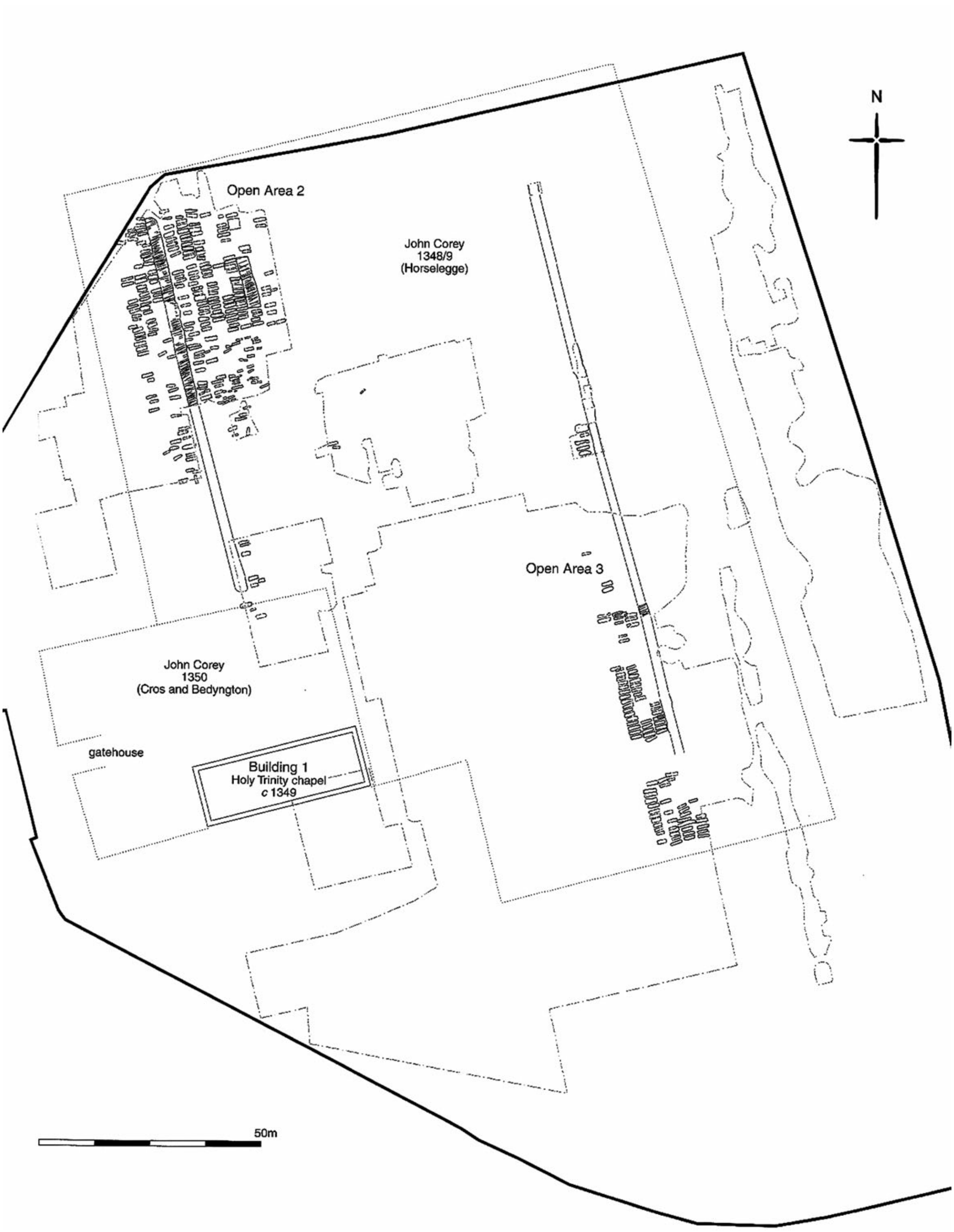

Fig. 2. Detail map of East Smithfield Cemetery, showing western and eastern burial areas (Grainger et al., 2008).

The original number of interments is estimated to have been around 2,400, although the total number of excavated individuals was 759 (Grainger et al., 2008); many were estimated to be lost to preservation issues (Hawkins, 1990). Of the 759 excavated individuals, 634 have been previously studied, comprising 186 males, 105 women (sex ratio of 1.77:1), 129 unsexed adults, and 214 subadults (Grainger et al., 2008).

The aims of this study are:

1. To characterize London mobility in the early to mid-14th century through the use of strontium and oxygen stable isotope analyses.
2. To attempt to provide a contextualized approach to the study of mobility in the 14th century which will include a consideration of the various crises facing the population during this period.
3. To test general assumptions about the demographics of migration against the realities of nonlocals in the East Smithfield skeletal assemblage and contribute further data to the determination of an expected ‘‘local’’ range for human remains.

MATERIALS

Past assumptions about differences between male and female mobility differentials, particularly in periods of stress such as famine, were rejected in favor of a balanced sex ratio wherever possible. Disarticulated human permanent teeth were drawn from a predetermined research sample from East Smithfield, with males and females in four adult age categories represented: 18–25 years, 26–35 years, 36–45 years, and greater than 46 years of age, based on previous aging and sexing data (Museum of London, 2007). Juvenile remains were unavailable for this study. Thirty individuals were sampled, with enamel being collected from a single tooth in each case. The age distribution of the sample was weighted toward the 26– 35-year-old age group, as both potentially the most likely age group to have been engaged in migratory activity at the time of death, and also the group which contained individuals with canine teeth mineralizing during the famine years of the 14th century.

Canine teeth were selected on the basis of availability and age of formation; the permanent canines form between birth and ~12 to 15 years of age, with the crown being completed by the age of ~6 to 7 years (Hillson, 1996). As the majority of the enamel input will have been completed after presumed average weaning age for the medieval period (Richards et al., 2002), it is reasonable to assume that measured $\delta^{18}O$ will reflect local values, rather than a raised trophic level due to a breastfeeding effect.

METHODS

Teeth were examined preparation for sampling, and any damage or pathological changes noted. The external enamel was then abraded with a tungsten carbide dental burr on a Kavo-4 drill to remove at least the outer 100 lm of enamel, the most likely layer to contain nonbiogenic isotopic material (Budd et al., 1998) and any existing calculus or other detritus. All teeth in the study were free of caries. A diamond-edged rotary dental saw was then used at 1,500 rpm to remove a 20–100 mg longitudinal (cusp to cemento-enamel junction) sample of enamel from the abraded surface of the tooth. A bulk sampling strategy using core enamel was preferred over microsampling for this study: although enamel mineralization timelines in most mammalian species (including human) are well defined, duration of enamel maturation (during which the majority of the biogenic isotopic input will occur) is not (Montgomery et al., 2010). Where possible to avoid unnecessary damage to the archaeological sample, previously collected enamel fragments were preferentially used. In all cases, any adhering dentine was drilled off, and all internal and external surfaces were cleaned with a burr. Tools were cleaned thoroughly with deionized water and methanol in between samples. Core enamel samples were then divided and allocated for $^{87}Sr/^{86}Sr$ and carbonate $\delta^{18}O$ analyses. All work was performed at NERC Isotope Geosciences Laboratory (NIGL), Keyworth, UK.

Strontium

Samples were transferred to a clean laboratory (Class 100, laminar flow) for preparatory chemistry. Isotope dilution was used to obtain strontium concentrations, using ^{84}Sr spike. Strontium was separated using quartz resin-filled (Dowex) columns. Analysis was performed in a clean laboratory on a Triton Thermo Finnegan multicollector mass spectrometer using Thermal Ionization Mass Spectroscopy. Single rhenium filaments were prepared following the method of Birck (1986). The international standard for $^{87}Sr/^{86}Sr$, NBS987, gave a value of 0.71025 +/- 0.00001 (n = 16, 2σ), producing an external reproducibility of +/- 0.0013% during the analysis of these samples. Dickin (2004) suggests that optimal precision for Sr isotope dilution stands at about one per mil (0.1%); however, as Montgomery (2002) demonstrated that intra-enamel heterogeneity for Sr concentration varies +/- 10%, no interpretations of difference will be made below this level.

Oxygen

Thirty enamel samples reserved for carbonate $\delta^{18}O$ analysis were crushed individually with a marble mortar and pestle to a fine powder, and the powder weighed out using a Sartorius M2P analytical balance into glass vessels in ~2.5 mg samples. Four 1–1.5 mg samples of SME, an in-house bioapatite reference standard, were included in the batch, as were eight samples measuring 50–100 µg each of in-house carbonate reference material (KCM), calibrated against NBS19 certified reference material to enable normalization to the PDB scale (Evans, 2011, pers. comm.). All tools and surfaces were cleaned between samples. Samples were transferred in their vials to a hot block at 90°C on a GV Multiprep system, where they were each reacted with 4 drops of anhydrous phosphoric acid. Resulting carbon dioxide was accumulated and cryogenically purified for 14 min before being introduced to the GV IsoPrime dual inlet mass spectrometer. Internal reproducibility of enamel duplicates run was +/- 0.2% (1σ) (Evans, 2011, pers. comm.).

RESULTS

Results for strontium and oxygen isotope analysis are summarized in Table 1. Carbonate $\delta^{18}O$ values are reported per mil, relative to Standard Mean Ocean Water (SMOW), using the equation of Coplen (1988): SMOW = (1.03091 x $\delta^{18}O$ PDB) + 30.91. Conversion from carbonate ($\delta^{18}O_c$) to phosphate ($\delta^{18}O_p$) oxygen isotope values was accomplished using the equation published by Chenery et al. (2012): $\delta^{18}O_p = 1.0322 \times \delta^{18}O_c - 9.6849$.

Despite valid concerns about the limited applicability and wide error ranges of drinking water calibrations (Millard, 2004; Pollard et al., 2011), data were converted to drinking water values for reference (Table 2) using the published equations of Longinelli (1984), Daux et al. (2008), and Chenery et al. (2012). Supporting Information Figures S1 and S2 show the expected geographical distribution of British biosphere strontium isotope ratios (Evans et al., 2010) and modern $\delta^{18}O$ drinking water values (Darling et al., 2003), respectively, and are included in Supporting Information for comparison with the following data.

The bivariate data were plotted using both age and sex variables (Fig. 3). Five outliers were identified visually using this combined plot in conjunction with box plot results (Figs. 4–6): three males (EK 5285, EK 5281, and EK11944) and two females (EK 6467 and EK 7163). Three further individuals were visually identified in Figure 3 as falling outside of the main cluster of data points (EK 11627, EK 8427, and EK 5291) and having $^{87}Sr/^{86}Sr$ that were below the expected local geological range (Evans et al., 2010), but were not determined to be statistical outliers, and will hence only be grouped into the broader category of ‘extreme individuals.’ All extreme individuals came from the three youngest age cohorts; none were observed from either sex in the 46+ age category.

TABLE 1. Strontium and oxygen isotope data for East Smithfield sample (N/A denotes data not available)

Sample	Sex	Age	Sr ppm	$^{87}Sr/^{86}Sr$	$\delta^{18}O_c$(SMOW)‰	$\delta^{18}O_p$ (SMOW)‰
EK 11109	F	18–25	139	0.70895	26.6	17.6
EK 11244	F	18–25	125	0.70926	26.5	17.5
EK 6467	F	18–25	93.2	0.70910	25.5	16.5
EK 11627	M	18–25	203	0.70837	26.1	17.0
EK 12815	M	18–25	161	0.70907	26.1	17.1
EK 7094	M	18–25	50.4	0.70915	26.5	17.5
EK 5283	F	26–35	95.7	0.70875	27.1	18.1
EK 5902	F	26–35	62.0	0.70927	27.1	18.0
EK 8427	F	26–35	69.5	0.70841	26.9	17.8
EK 12566	M	26–35	98.5	0.70989	26.3	17.3
EK 5281	M	26–35	64.7	0.71167	27.5	18.4
EK 5291	M	26–35	174	0.70809	26.6	17.6
EK 11430	F	36–45	124	0.70899	26.8	17.8
EK 12814	F	36–45	97.1	0.70902	27.5	18.4
EK 5326	F	36–45	123	0.70976	26.7	17.6
EK 5741	F	36–45	101	0.70989	27.0	17.9
EK 7163	F	36–45	N/A	N/A	28.1	19.1
EK 7381	F	36–45	90.4	0.70960	27.2	18.1
EK 11115	M	36–45	112	0.70965	27.1	18.1
EK 11118	M	36–45	144	0.70898	26.0	17.0
EK 11914	M	36–45	82.9	0.70886	27.5	18.5
EK 11944	M	36–45	189	0.70940	28.2	19.1
EK 5285	M	36–45	115	0.70873	25.2	16.2
EK 5960	M	36–45	111	0.70922	26.9	17.8
EK 12790	F	461	109	0.70989	27.0	18.0
EK 11193	M	461	98.2	0.70989	26.5	17.5
EK 12567	M	461	178	0.70900	26.5	17.4
EK 12813	M	461	118	0.70939	26.9	17.9
EK 20003	M	461	66.1	0.70886	26.7	17.6
EK 5272	M	461	93.6	0.70866	26.7	17.7
Mean			112	0.70920	26.8	17.7
1r			39	0.0007	0.7	0.7

TABLE 2. Oxygen isotope values for East Smithfield sample with conversions to drinking water values

Sample	Age	Sex	$\delta^{18}O_c$ (SMOW)‰	$\delta^{18}O_p$ (SMOW)‰	Longinelli (1984)‰	Daux et al., Eq. (6) (2008)‰	Chenery et al. (2012)‰
EK 11109	18–25	F	26.6	17.8	27.2	26.4	26.3
EK 6467	18–25	F	25.5	17.7	27.4	26.5	28.1
EK 11244	18–25	F	26.5	16.6	29.0	28.1	26.5
EK 11627	18–25	M	26.1	17.2	28.1	27.2	27.2
EK 12815	18–25	M	26.1	17.3	27.9	27.1	27.1
EK 7094	18–25	M	26.5	17.7	27.4	26.5	26.5
EK 5283	26–35	F	27.1	18.3	26.3	25.5	25.5
EK 5902	26–35	F	27.1	18.3	26.4	25.6	25.6
EK 8427	26–35	F	26.9	18.1	26.7	25.9	25.9
EK 12566	26–35	M	26.3	18.7	25.8	24.9	26.8
EK 5291	26–35	M	26.6	17.8	27.2	26.4	26.4
EK 5281	26–35	M	27.5	17.5	27.7	26.8	24.9
EK 11430	36–45	F	26.8	18.0	26.8	26.0	26.0
EK 12814	36–45	F	27.5	18.7	25.8	25.0	25.0
EK 5326	36–45	F	26.7	17.8	27.1	26.2	26.2
EK 5741	36–45	F	27.0	18.1	26.6	25.8	25.8
EK 7163	36–45	F	28.1	18.4	26.2	25.4	23.9
EK 7381	36–45	F	27.2	19.4	24.7	23.9	25.4
EK 11115	36–45	M	27.1	18.3	26.4	25.6	25.6
EK 11118	36–45	M	26.0	17.2	28.2	27.3	27.3
EK 11914	36–45	M	27.5	18.7	25.7	24.9	24.8
EK 11944	36–45	M	28.2	19.4	24.6	23.8	23.8
EK 5285	36–45	M	25.2	16.3	29.5	28.7	28.6
EK 5960	36–45	M	26.9	18.0	26.8	25.9	25.9
EK 12790	461	F	27.0	18.2	26.5	25.7	25.7
EK 11193	461	M	26.5	17.7	27.4	26.5	26.5
EK 12567	461	M	26.5	18.1	26.7	25.9	26.6
EK 12813	461	M	26.9	17.8	27.1	26.3	25.8
EK 20003	461	M	26.7	17.6	27.4	26.6	26.2
EK 5272	461	M	26.7	17.9	27.0	26.2	26.2
Mean		26.8	17.9	26.9	26.1	26.1	Mean
1r		0.7	0.7	1.1	1.0	1.0	1r

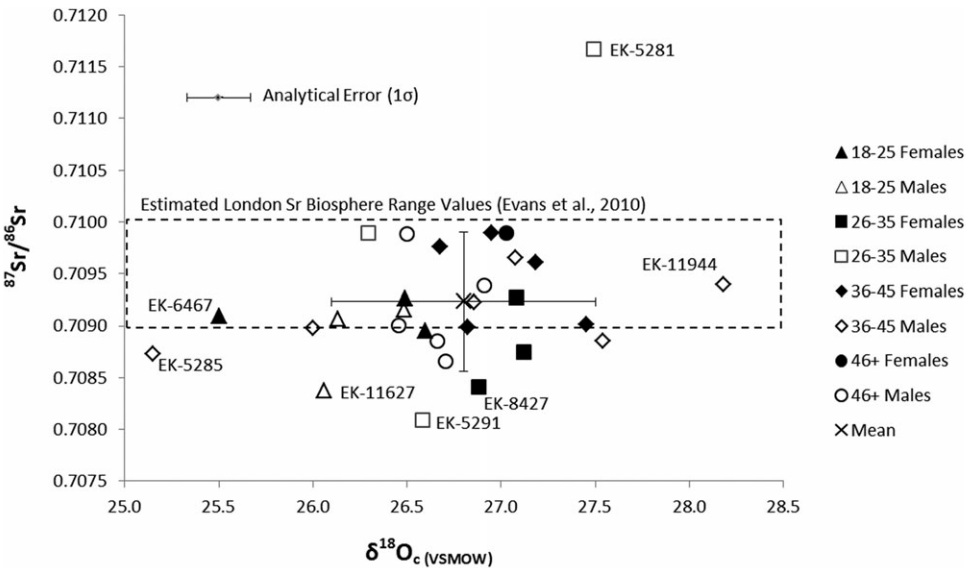

Fig. 3. Plot of strontium and oxygen isotope data for East Smithfield by age and sex, ($^{87}Sr/^{86}Sr$). 2σ analytical error bars smaller than symbol, mean error bars shown at 1σ).

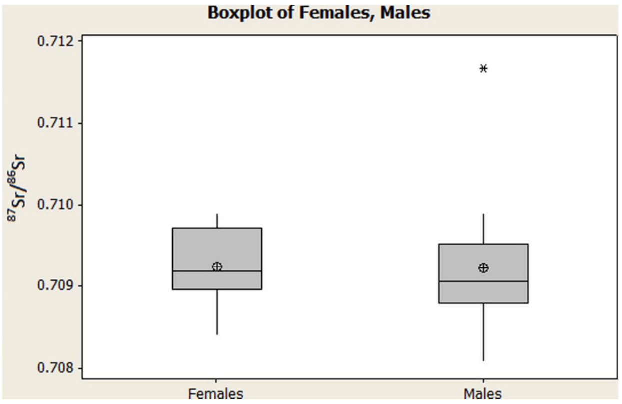

Fig. 4. Box plot of $^{87}Sr/^{86}Sr$ in East Smithfield sample by sex (mean is denoted by round symbol, line denotes median).

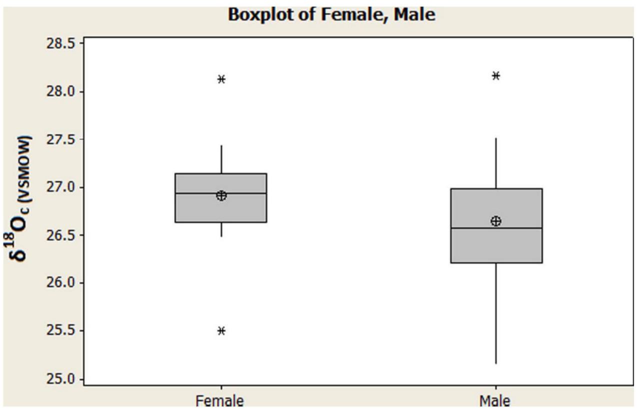

Fig. 5. Box plot of $\delta^{18}O$ in East Smithfield sample by sex (mean is denoted by round symbol, line denotes median).

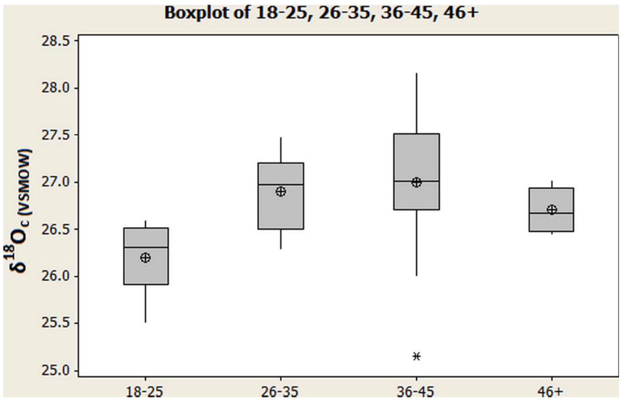

Fig. 6. Box plot of $\delta^{18}O$ in East Smithfield sample by age (mean is denoted by round symbol, line denotes median).

DISCUSSION

Defining the local range

One accepted method of identifying nonlocals or migrants from isotopic data is to define the local rangeby creating a cut-off point at two standard deviations from the sample mean (e.g., Price et al., 1994; Grupe et al., 1997; Bentley et al., 2004). For the East Smithfield population, this would imply a local strontium range of 0.7079 to 0.7106 (0.7092 +/- 0.0014). Although this range certainly includes most sample values, it is too broad to be useful as an indicator of the local range: it would include not only estimated values found over most of southern Britain but also some found only in isolated areas of western Scotland (Evans et al., 2010). This approach additionally assumes that local Sr ratios will be normally distributed within the population, a supposition unlikely to be supported in isotopic end-member systems (Montgomery et al., 2007). Figure 7 shows plotted data for the East Smithfield sample, with a two sigma range applied to mean $\delta^{18}O$ (25.4‰–28.2‰). Approaching the identification of a local 'fingerprint' through this method has the potential to create over-inclusivity, as it incorporates individuals with $\delta^{18}O$ elsewhere identified as categorically anomalous for this population by statistical methods.

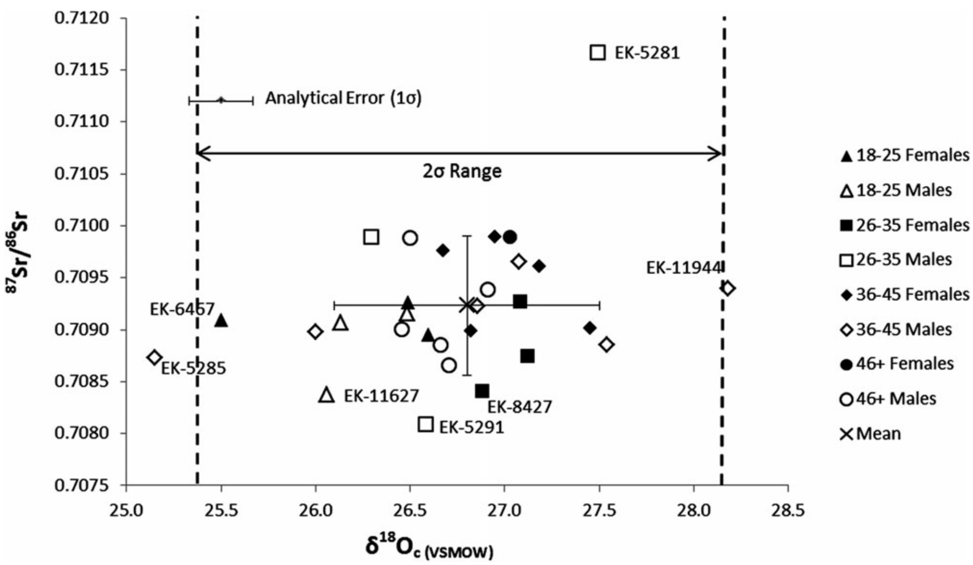

Fig. 7. Bivariate plot of data showing 2σ "local" $\delta^{18}O$ range from mean (dashed line indicates 2σ range. Mean error bars and analytical error for $\delta^{18}O$ shown at 1σ, $^{87}Sr/^{86}Sr$ error within symbol).

A second strategy is to define the local range using local, contemporary archaeological animal bone as a measure of bioavailable isotopes. This is considered by some to be a preferable approach (Bentley et al., 2004), but outside the scope of this study as animal bone was unavailable. Additionally, it is a difficult approach to apply to Medieval London, as animal bone must be reliably local and contemporary; animals large enough to have survived in the archaeological record (i.e., meat animals) are quite likely to have been reared outside the city and brought to London markets for slaughter during this period, as was common practice (Keene, 1989; Galloway and Murphy, 1991). Therefore a third approach, statistical identification of population norms and outliers derived from the isotopic data itself, has been preferred here. Pollard (2011) argues that this a posteriori approach is preferable to imposition of external geology-based isotope boundaries. Evans et al. (2010) defined the expected Sr ratio range for the London clay biosphere as being 0.709 to 0.710 (0.7097 +/- 0.0007, n = 14) based on plant-derived measures of biosphere Sr; however, a strict application of this lower limit would exclude nearly half of the data in the East Smithfield sample.

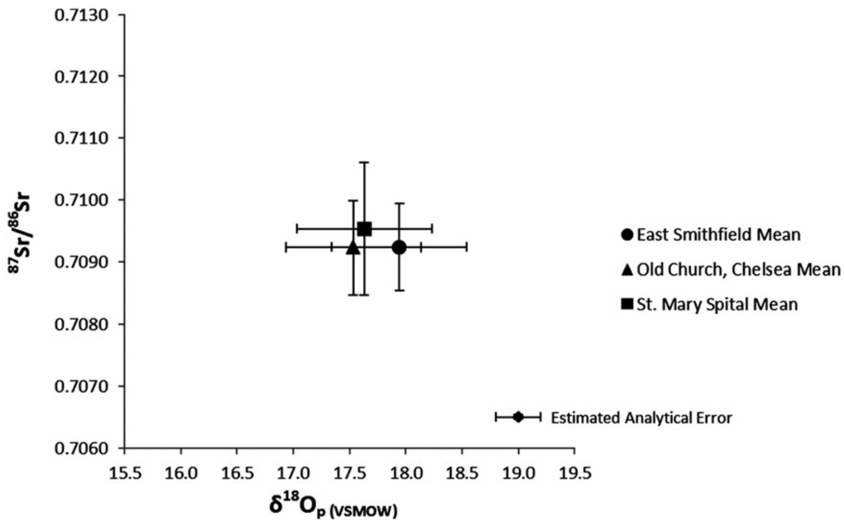

Fig. 8. Means of three post-Roman London datasets (mean error bars and analytical error for $\delta^{18}O$ shown at 1σ, analytical error for $^{87}Sr/^{86}Sr$ at 2σ within symbol).

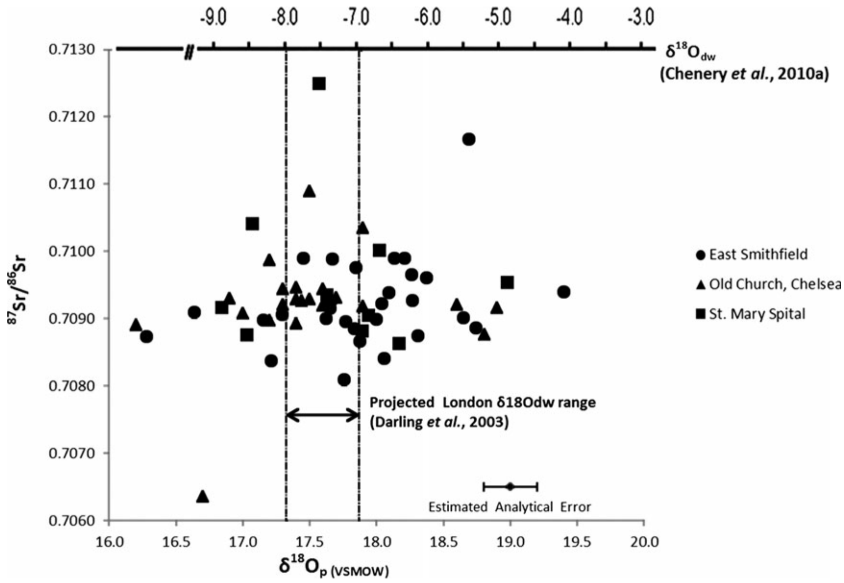

Fig. 9. Plot of isotope data for East Smithfield, Chelsea (Trickett, 2006), and St. Mary Spital (Lakin, 2009), (estimated 2σ analytical error bars within symbol for $^{87}Sr/^{86}Sr$).

Lakin (2010) attempted to characterize London biosphere Sr ratios by analyzing diagenetically altered human dentine from St. Mary Spital, a medieval cemetery site. In the absence of other materials, such as soil leachates or animal bone, she found that the dentine values tentatively suggested a far less radiogenic lower limit, or a new local range of 0.7086 to 0.7100 (Lakin, 2010). This $^{87}Sr/^{86}Sr$ range fits well with the East Smithfield population sample, allowing for the inclusion of eight individuals belonging to the plotted cluster of central data points, who would have been excluded from the previously defined local range of 0.709–0.710. However, it is important not to place too much significance on these dentine results; they are derived from a very small sample, and it is not possible to determine how close to equilibrium with soil values the dentine has come without evidence from soil leachates. The fact nonetheless remains that the observed biogenic ''local'' range of $^{87}Sr/^{86}Sr$ for human enamel samples at East Smithfield as determined by statistical analysis falls outside the limits of the expected geological range (Evans et al., 2010). Comparative data from London is somewhat limited in availability. Two doctoral theses have been completed using strontium and oxygen isotope analyses on post-Roman London samples. Trickett (2006) compared postmedieval populations from Coventry and Old Church, Chelsea (18th–19th Centuries), while Lakin (2010) measured strontium and oxygen isotopes from a medieval (12th–16th Centuries) sample at St. Mary Spital, London. Data from both samples have been compared with the East Smithfield data. Mean Sr ratios, mean Sr concentration, and mean $\delta^{18}O_p$ are very similar for all three sites (Table 3). This similarity of character is further sustained by plots of sample means and standard deviations (Fig. 8) and total data from all three sites (Fig. 9), demonstrating a clear overlap between the datasets. Why might this broader range be exhibited in these populations? The answer to this question may lie in medieval food sourcing practices for the London area.

Although smallholdings in medieval cities were common, estimates of 14th-century London population (80,000–100,000) suggest that, far from being self-sufficient, the capital would have been largely reliant on its hinterlands for agricultural produce such as meat, dairy, and grain (Campbell et al., 1992). London completely dominated its region in many respects, as a ''rapacious'' consumer of regional resources (Galloway and Murphy, 1991, p. 3), as well as a thriving center for trade and industry (Keene, 1989). Grain, in particular, was a staple of the medieval peasant diet which was primarily grown outside London on manorial estates and transported to the city via the Thames or overland (Galloway and Murphy, 1991). Henley (Oxfordshire) was a major receiver of grain from manors in Oxfordshire and Buckinghamshire in advance of transport to the capital for sale in the markets. Other ports and granaries supplied Chiltern wheat and barley (Galloway and Murphy, 1991). Fruits and vegetables tended to be produced in the London environs due to their perishability, while dairy products such as cheese and butter were commonly sourced in Essex and Suffolk (Galloway and Murphy, 1991). The introduction of large amounts of grain grown on soils with underlying chalk substrates—ratios of 0.708 to 0.709 (Evans et al., 2010)—into the local diet would certainly have the potential to have shifted the local 14th century biogenic strontium ratios into a less radiogenic range than the local geology would suggest. The complexity of nutritional sources in an urban market economy is a recognized problem in dietary isotopic study (Muldner and Richards, 2005) and should be considered in provenance studies as well, which also reflect dietary input. This very dietary and economic complexity underlines the importance of well-defined temporal resolution in the interpretation of mobility, as well as dietary, isotopic studies: without the secure and narrow dating of East Smithfield Black Death cemetery, it may not have been possible to suggest and interpret mixing factors with any degree of confidence, since trade sources and networks may alter greatly over a use-period measured in hundreds of years.

TABLE 3. Comparative strontium and oxygen isotope data for London from three post-Roman studies

Study	**Site**	**Mean Sr ppm**	**Mean $^{87}Sr/^{86}Sr$**	**Mean $\delta^{18}O_p$ ‰**
Kendall (2011)	East Smithfield	112	0.70924	17.9
Trickett (2006)	Old Church Chelsea	125	0.70924	17.5
Lakin (2010)	St Mary Spital	104	0.70954	17.6

Medieval mobility and ''nonlocals''

It is perhaps unsurprising that, in a sample of 30 individuals from a city as dependent on immigration and trade as medieval London (Childs, 2006), eight individuals appear isotopically anomalous for this dataset: EK 5285, EK 5281, EK11944, EK 6467, EK 7163, EK 11627,

EK 5291, and EK 8427. All individuals fall outside the central cluster of plotted data. The advantage of using a two-isotope approach for mobility studies is well illustrated by this sample: only one individual was identified as an outlier (EK 5281) when constructing box plots with $^{87}Sr/^{86}Sr$ measurements alone, while the addition of plots using $\delta^{18}O$ data highlights the existence of four further outliers (EK 5285, EK 11944, EK 6467, and EK 7163). Only three of the individuals, visually distinct from the plotted central cluster (EK 11627, EK 8427, and EK 5291), failed to be substantiated as having significantly anomalous isotope values, despite low $^{87}Sr/^{86}Sr$ (\0.7085) for the expected local range. These individuals cannot therefore be positively identified as outliers, although they are certainly unusual for the sample, and their strontium values are very unlikely to be produced by the geology of the London clays.

Although it is impossible to definitively ascertain childhood geographical origin with isotopic data, as they do not directly prove provenance of people but rather provenance of childhood dietary and hydrological inputs (Bentley, 2006), it is potentially feasible to explore likelihoods based on a consistency between isotopic composition and historical relationships. The individuals with low $^{87}Sr/^{86}Sr$ (EK 11627, EK 8427, and EK 5291) exhibit ratios consistent with the chalk substrate areas (0.7080– 0.7090) which underlie and surround the London clays, as well as the region surrounding the Humber estuary and Yorkshire (Evans et al., 2010). It is interesting to note that there was a prominent stream of known migration from densely populated Norfolk, an area consistent geologically with measured values, during this period (Keene, 1989). These ratios are also consistent with Jurassic limestone lithologies found in central England (Evans et al., 2010). Proximity to London and knowledge of the frequent interactions between the city and its hinterlands makes the chalklands a feasible origin for EK 5291. EK 11627 and EK 8427 may also have come from this area, but as it is not possible to positively demonstrate nonlocal status for these individuals, this suggestion must remain tentative. The youth of these three individuals—all were roughly estimated as being under the age of 36—suggests that they were unlikely to have been affected by recorded famine subsequent to their enamel formation period. War is also unlikely to have been a motivator for migration during a period of recorded peace (Aberth, 2000), especially for EK 8427, a 25–36-year-old female. However, males and females were equally eligible to compete in the labor market and are documented to have done so in other medieval British cities (Muldner and Richards, 2007), while economic pressures are the primary causal factors in the majority of significant-distance migrations (Lewis, 1982).

The high Sr outlier, EK 5281, was a male between 26 and 35 years of age. His $^{87}Sr/^{86}Sr$ of 0.71167 is too radiogenic to be compatible with a childhood spent in the London environs, or anywhere in southern England, suggesting a far older underlying geology. It is, however, compatible with some areas of southern and western Wales, the full extent of the Pennines, and the southern lowlands and central belt of Scotland, based on environmental samples (Evans et al., 2010). Oxygen isotope data could potentially clarify the picture, as the locations consistent with the measured Sr ratios are sufficiently distant from London to be potentially distinguishable from each other based on $\delta^{18}O$ values. His $\delta^{18}O_{dw}$ suggests a more westerly origin than London, such as Wales, but with the variation in drinking water conversions, compounded by the potential error added by converting carbonate oxygen isotope to phosphate oxygen isotope values, it is best to be cautious in this interpretation, especially as his $\delta^{18}O$ value was not shown to be statistically different from the ''local'' range in this sample. Of the areas consistent with the $^{87}Sr/^{86}Sr$ values of EK 5281, it is tempting to allocate the area of greatest proximity to London as the likely candidate for his origin: however, in the absence of historical data preferring one location over another, it would be irresponsible to attempt to do so definitively. Pollard (2011) has commented on the propensity of research in scientific archaeology to transform from production of nuanced and fluid models to clear and certain absolutes in the popular imagination: this is a misapprehension that should be strongly discouraged. Preferring one location based on geographical convenience would also ignore a body of historical evidence to the contrary; distance was not the strongest factor in migration to London, which drew the largest proportion of its migrants from an average of 40 miles distant, in contrast to the usual maximum of 20 miles for most urban districts (Keene, 1989). Rather, migration pressures were complex during this period, and unrestricted by modern preconceptions of the difficulty of long-distance travel during this period. London possessed a high proportion of foreigners, particularly Germans and Flemings, among its migrant populations (Keene, 1989), demonstrating the strength of attraction of the English capital city.

The four remaining anomalous individuals, EK 6467, EK 5285, EK 7163, and EK 11944, appeared consistent in terms of their Sr ratios with the London biosphere, but plotted clearly outside the central cluster of oxygen isotope ratios. All four appeared as outliers in the oxygen isotope box plots. Despite concerns about the precision of drinking water conversion equations (Millard, 2004; Pollard et al., 2011; Chenery et al., 2012); which may produce errors ranging from +/- 1.0‰ to +/- 3.5‰ (Pollard et al., 2011), as well as additional error (+/- 0.28‰) introduced by the extra conversion from carbonate to phosphate oxygen (Chenery et al., 2012); data was converted to drinking water values using four extant calibration equations in the hope of identifying potential childhood origin of these three individuals through comparison with Darling et al.'s (2003) drinking water isotope map. One of these equations, recently published by Chenery et al. (2012), accomplishes the conversion of drinking water values directly from carbonate oxygen values and can therefore be expected to eliminate a level of additional error from the calculations. Nonetheless, calibration equations produce highly variable results which often correlate with multiple regions on the drinking water oxygen isotope map for a single individual.

Oxygen isotope data should always be interpreted with caution due to the number of factors other than nonlocal provenance which may influence oxygen isotope measurements from archaeological human enamel: fluctuations in climate, evaporation or processing of imbibed fluids, analytical precision, and natural population variation may all produce human values which deviate from an expected norm (Evans et al., 2012). Puceat et al. (2010) found as much as two per mil variation in phosphate oxygen isotopes measured in bones from fish raised within the same controlled-environment tank, and it is to be reasonably assumed that human environments, being less controlled, would produce a significant level of within-population variation. Similarly, human dietary behavior may also produce variation in oxygen isotopes measured in enamel; although natural evaporative processes do not significantly alter the $\delta^{18}O$ values of drinking water (Evans et al., 2012), consumption of brewed alcoholic drinks, boiled drinks, and stewed foods may enrich the $\delta^{18}O$ of human enamel by as much as 2.3‰ (Brettell et al., 2012). Although most of these influences must be taken into account, climate change was not found to be a statistically significant factor in altered oxygen isotope values in this study; although the historical timeframe made the end of the MWP and the transition to the Little Ice Age a relevant consideration, a one-way analysis of variance (ANOVA) between the means of age cohorts found no significant differences ($P<0.05$).

For these reasons, drinking water values have not been used to predict specific childhood provenance but have been regarded more in the light of a general guide to west/east isotope gradients. Using these as a guide, two trends are seen with $\delta^{18}O_C$: low (EK 6467, 25.5‰; EK 5285, 25.2‰) and high (EK 7163, 28.1‰; EK 11944, 28.0‰) values. The low $\delta^{18}O$ values are consistent with areas of eastern Scotland and the area surrounding and

to the south of York; of these locations, their corresponding $^{87}Sr/^{86}Sr$ would be most consistent with the latter. The high $\delta^{18}O$ values match western British locations such as Devon, Cornwall, western Wales, and the western islands of Scotland. Of these locations, only Devon, Cornwall, isolated areas of the Welsh coast, and the extreme western fringe of the Western Isles of Scotland are consistent with both $\delta^{18}O$ and $^{87}Sr/^{86}Sr$. These $\delta^{18}O$ values are also unlikely to represent a climatic or cultural shift over time as although two of the high values are from the same (36–45) age category, one of the low outliers (EK 5285) also belongs to this age group. However, as the 36–45-year-olds in this group would have certainly lived through the Great Famine of 1315–1322, they may potentially represent famine-related migration. There is little published comparative carbonate oxygen isotope data for Britain. Nonetheless, one such study by Muldner et al. (2009) has produced carbonate oxygen isotope data for the medieval period using an attritional cemetery sample from Whithorn Cathedral Priory (n = 14) in southwestern Scotland. The high East Smithfield outliers EK 7163 and EK 11944 have comparable $\delta^{18}O_C$ values with those seen at Whithorn (mean value 28.1‰ +/-0.6‰), supporting the case for these individuals potentially having origins to the western portion of Britain.

Too much must not be made of the data discussed: measured ''nonlocal'' isotopic signals imply merely nonlocal input to the individuals in childhood (Bentley, 2006). For a city as well-supplied with staple foodstuffs from exogenous origins as medieval London is documented to have been, it is reasonable to argue that a large proportion of staple dietary intake would likely have been external in origin, affecting the isotope ratios measured here. It is somewhat less likely to affect $\delta^{18}O$ values, as they are primarily determined by drinking water, a resource not easily transported even by modern means, than strontium isotope ratios. The possibility that 'chalkland migrants' were actually locals with an essentially nonlocal diet should be considered, although it is likely, given historical evidence, that they were migrants from London's hinterlands.

Without better resolution in aging methods, and further comparative isotopic data, it is difficult to align these examples of potential mobility with any of the migration pressures of the 14th century with any degree of certainty. However, this dataset is as interesting for the characterization of late-Medieval London norms as it is for the illustration of deviance from them. This study represents the largest body of strontium and oxygen isotope data for late Medieval London to date. There is currently little published comparative combined strontium and oxygen isotope data for post-Roman London and this study, as an application of these analyses to the late medieval period, is one of only a small number of extant studies (Muldner et al., 2009). Hopefully, in the near future this gap in data will be remedied and our understanding of the era preceding the declines of the late medieval period will be broadened.

CONCLUSION

The stated goal of this research was to produce a contextualized picture of mobility in the mid to late-14th century using oxygen and strontium stable isotope analyses in conjunction with available historical documentary research. Precise documentary dating of the East Smithfield catastrophic cemetery, unusual among archaeological burial grounds has provided a rare opportunity to contextualize mobility and local isotopic norms for what was an unusually turbulent period of Western European history. A use-life of only 2 years, spanning 1348–1350 has also allowed alignment of documented major historical events with the possible years in which the East Smithfield population lived.

Eight out of 30 individuals sampled demonstrated unusual isotopic values; of these, five were shown to be outliers by various statistical methods, a high proportion of the sample. Some of these potentially spent their childhood at great distances from London, a possibility which is in keeping with the strength of attraction wielded by the capital city (Keene, 1989). Migration has been documented historically as being incredibly important to the health of major cities in general, and London in particular (Keene, 1989; Childs, 2006), while various historical events such as the Great Famine may have increased migration pressures further. It is therefore reassuring to see that the level of migrant representation in this small sample is consistent with the significance and scale of migration suggested by historical documents.

Predicted patterns of sample distribution have not been supported; sex ratios were near to equality. Their numbers are far too small to demonstrate significance, or to allow definitive statements about sex differences in migratory activity to be made with any validity. However, the presence of female nonlocals in the sample refutes the concept of migration during this period being an exclusively male prerogative. Using a combined biogeochemical approach incorporating both oxygen and strontium isotopes has greatly aided detection of nonlocals by allowing a much more comprehensive identification of outliers in this sample than would have been available using a single-isotope strategy.

The dataset produced by this study is significant, not only for the aforementioned detection of 'nonlocals,' but also for the characterization of the medieval London isotopic range. Movement of resources, as well as people, is an important factor to consider. Human beings are not simply passive consumers of raw, locally available resources; they are active consumers of traded and culturally modified products resulting from their interaction with a living and changeable environment. This dynamic between culture, biology, and environment becomes an essential point to acknowledge when dealing with an urban market economy such as medieval London; more than external determinants are involved in the processes which result in archaeological isotopic data and it does not pay to underestimate the role of human agency.

Despite the lack of supporting data for the local $^{87}Sr/^{86}Sr$ range from sources such as soil leachates and contemporary local animal bone, this study has substantially expanded the available human data for reference. Due to the complex network of mixing factors and cultural behaviors which result in the isotope data measured in archaeological human remains, it may indeed be better to use direct methods of measuring these behaviors (i.e., a large body of human remains-derived data), than proxy measures of contemporary ''localness'' using other species or underlying geology. Oxygen stable isotopes are also an area of research in need of more comparative human datasets, particularly in regard to carbonate oxygen isotope data. Greater publication of comparative datasets is essential to the precision and usage of the future application of this type of data to migration studies. Regardless of this need for future contributions to further the development of British archaeological mobility studies, this study has benefited from an unusual opportunity to put data within a well-defined historical context, and has therefore contributed new insights into the migration patterns of 14th century London.

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